



DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

AUG 7 2002

FROM: HQ AFCESA/CES
139 Barnes Drive, Suite 1
Tyndall AFB, FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 02-7: Preventing Concrete Deterioration Under B-1 and F/A-18 Aircraft**

1. Purpose. This ETL details the results of several strategies to mitigate concrete deterioration under B-1 Lancer and F/A-18 Hornet aircraft auxiliary power unit (APU) exhaust ports.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Application. This ETL is applicable to pavements possessing a combination of heat and chemical resistance for use under B-1 aircraft.

2.1. Authority: Unified Facilities Criteria (UFC) 3-260-02, *Pavement Design for Airfields*.

2.2. Effective Date: Immediately.

2.3. Ultimate Recipients:

- Major command (MAJCOM) engineers
- Base civil engineers (BCE) and other engineers responsible for airfield design and maintenance
- U.S. Army Corps of Engineers (USACE) and Navy offices responsible for Air Force design and construction

2.4. Coordination: MAJCOM pavement engineers.

3. Referenced Publications.

3.1. Unified Facilities Criteria (UFC):

- UFC 3-260-02, *Pavement Design for Airfields*

3.2. Navy:

- Naval Facilities Engineering Service Center (NFESC) Tech Data Sheet (TDS) 2058-SHR, *A Concrete Solution to the F/A-18 Parking Apron Problem*, September 1998
- Hironaka, M.C., Malvar, L.J., "Jet Exhaust Damaged Concrete," *Concrete International*, vol. 20, no. 10, October 1998, pp. 32-35

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3.3. Federal Specifications (FS):

- FS SS-S-200E, *Sealants, Joint, Two-Component, Jet-Blast Resistant, Cold-Applied*
- FS SS-S-1614, *Sealants, Joint, Jet-Fuel Resistant, Hot-Applied*

3.4. Private Industry:

- Anderson, John R., Marian P. Rollings, Michael Ayers, and Raymond S. Rollings. *Auxiliary Power Unit (APU) Resistant Concrete: State-Of-The-Art*. Transportation Systems 2000 Conference, San Antonio, Texas, 1 March 2000
- McVay, Michael, Jeff Rish III, Chris Sakezles, Shaik Mohseen, and Charles Beatty. "Cements Resistant to Synthetic Oil, Hydraulic Fluid, and Elevated Temperature Environments." *ACI Materials Journal*, March-April 1995: 155-163

4. Acronyms and Terms:

ACI	- American Concrete Institute
AFB	- Air Force Base
APU	- auxiliary power unit
BCE	- base civil engineer
CES	- Civil Engineer Squadron
ETL	- Engineering Technical Letter
FOD	- foreign object damage
FS	- Federal Specification
JTF	- jet turbine fluid
MAJCOM	- major command
NAS	- Naval Air Station
NFESC	- Naval Facilities Engineering Service Center
PCC	- Portland cement concrete
TDS	- Tech Data Sheet
UFC	- Unified Facilities Criteria
USACE	- U.S. Army Corps of Engineers

5. Definitions:

5.1. E-Krete™. E-Krete™ is a water-based polymer latex composite coating containing aggregate. E-Krete™ products are designed to provide a wearing surface that is durable and abrasion- and fuel-resistant for sealing pavement surfaces. E-Krete™ is applied using a flooding/squeegee/brush applicator, which can be followed by an aggregate chip layer if desired. Thickness can range from 1.5 to 6 millimeters (0.0625 to 0.25 inch), depending on the formulation and number of coats. A surface sealer (either solvent or water-based) may be applied to E-Krete™ to enhance the fuel/oil/chemical resistance in areas where an additional level of protection is warranted, such as aircraft parking areas or parking garages.

E-Krete™ is manufactured by Polycon, Inc., 300 Industrial Drive S., Madison, MS 39110, (601) 898-1024.

5.2. Surtreat®. Surtreat® is a family of products used to restore Portland cement concrete (PCC) structures. These products are used on a case-by-case basis depending on the properties of the concrete and the specific rehabilitation needed. Surtreat® formulations reportedly penetrate and solidify inside concrete porous cavities and chemically react with the cement phase of concrete to increase hardness and strength, and decrease permeability. They are reported to render concrete inert to attack and penetration by acids, bases, and other aggressive chemical solutions. Surtreat® is not a coating; it becomes part of the structure and cannot be scratched, peeled, or otherwise removed from the surface. Some Surtreat® products are designed to purge contaminants (e.g., oils, salts, acids) and seal the surface to prevent future penetration. Surtreat® may be used as a surface preparation treatment to improve adhesive properties of concrete before repairs or coating.

Surtreat® is available from the Surtreat Corporation, 1360 N. Wood Dale Road, Suite A, Wood Dale, IL 60191, (630) 616-2757.

5.3. Magnesium Phosphate Cement (MPC). MPC is a different cement formulation than conventional PCC. MPC is less sensitive to reaction with acids than PCC. It can be extended with any normal aggregate; however, for applications under B-1 aircraft, using aggregate that is not reactive with acids (such as limestone) is necessary. MPC is a fast-setting cement that reaches high strength (above 34.5 megapascals [5000 pounds per square inch]) in less than one hour, with an ultimate strength after several hours of approximately 55.1 megapascals (8000 pounds per square inch). It is more resistant to the types of aviation fluids that have caused damage to pavement under Navy F/A-18 Hornet fighter aircraft (Naval Facilities Engineering Service Center [NFESC] Tech Data Sheet [TDS] 2058-SHR, *A Concrete Solution to the F/A-18 Parking Apron Problem*).

MPC is available as Set 45™ from ChemRex, 889 Valley Park Drive, Shakopee, MN 55379, telephone (952) 496-6000, FAX (952) 496-6062, Customer Service (800) 433-9517, Technical Services (800) ChemRex (243-6739).

6. Introduction.

6.1. This ETL summarizes the laboratory testing and field observations (see Attachment 1) of different strategies used to prevent pavement damage under B-1 and F/A-18 aircraft due to APU exhaust heat catalyzing a reaction between jet turbine fluid (JTF) and the PCC binder in concrete pavements. B-1 aircraft bed-down areas at McConnell, Dyess, and Robins Air Force Bases (AFB) have been inspected; Ellsworth and Edwards AFBs have not been inspected. After approximately one to two years of continuous use, concrete pavement begins to show signs of surface cracking that progresses to delamination of the surface paste, exposing the subsurface aggregate. Depending on the concrete finish, sheets of up to 12 millimeters (0.5 inch) thick may

delaminate, creating foreign object damage (FOD) potential. Eventually the cement paste loses all binding capacity and the concrete begins to ravel. If left unchecked, the depth of damage extends to several inches below the pavement surface (Anderson, et al., *APU Resistant Concrete: State-Of-The-Art*, Transportation Systems 2000 Conference, San Antonio, Texas, 1 March 2000).

6.2. Concrete deterioration under B-1 aircraft is similar to that under F/A-18 aircraft. The F/A-18 problem has been thoroughly studied by the Naval Facilities Engineering Service Center (NFESC) (Hironaka, M.C., Malvar, L.J., "Jet Exhaust Damaged Concrete," *Concrete International*, vol. 20, no. 10, October 1998, pp. 32-35). The problem is due to a combination of factors: thermal expansion from high APU temperatures; thermal gradients in the concrete; reaction between PCC paste and lubricating oils; and pore pressures generated by water inside the pavements. The most significant factors are the thermal expansion and chemical reaction. Thermal expansion can be lessened by using lightweight aggregates (NFESC TDS-2058-SHR). The chemical reaction can be mitigated by using MPC. Lubricating oils contain a chemical component called 'esters' and are found in high concentrations in JTF used in B-1 aircraft (McVay, et al., "Cements Resistant to Synthetic Oil, Hydraulic Fluid, and Elevated Temperature Environments," *ACI Materials Journal*, March-April 1995). B-1 aircraft are especially prone to JTF leaks that leach into concrete pavements underneath the aircraft. When the B-1 APU is operating, the pavement underneath the aircraft heats up, causing the esters present in the pavement to degrade. The degradation of the ester, termed hydrolysis, results in the production of an acid that can react with the cement paste. This acid-base reaction destroys the cement binder and eventually results in a loss of binding and structural capacity of the concrete, and the concrete pavement begins to crack and ravel.

6.3. Solutions for solving the thermal/fluid concrete degradation have been directed into four areas: heat-resistant concrete and chemical-resistant concrete that provides structural capacity; steel plates to deflect heat; and surface treatments that either penetrate or coat the concrete. Several different types of structural concrete types have been tested in the laboratory to determine the relative potential for APU damage. This testing showed that magnesium ammonium phosphate cement with a lightweight expanded shale aggregate performed best under laboratory conditions, outperforming all PCC mixtures (NFESC TDS-2058-SHR). The most cost-effective solution was determined to be a concrete mixture of ordinary PCC and lightweight aggregate. Reactive surface penetrants, such as Surtreat[®] used at McConnell and Robins AFB, have not been in use long enough to judge performance. Surtreat[®] has not been tested in the laboratory. Surface coatings such as E-Krete[™] have achieved mixed results at McConnell AFB. Laboratory studies of polyurea demonstrate excellent heat and chemical resistance but have not been tested in the field. Surface treatments require extensive cleaning of the concrete to provide a proper base for coating adhesion and to allow penetrants access to reactive sites within the concrete.

7. Mitigation Strategies.

7.1. The most successful of the field-tested options on Air Force facilities to prevent concrete deterioration to date is the use of MPC with a non-acid reactive aggregate. This option is being employed at Dyess AFB using a technique similar to partial-depth spall repair. Thin-bonded overlays (approximately 76 millimeters [3 inches] thick) of MPC (Set 45™) extended with a non-acid reactive basalt aggregate withstood two-and-a-half years of service without any signs of concrete deterioration. Several new B-1 pads have been replaced with MPC and have been in operation for approximately one year.

7.2. The most successful of the field-tested options on Navy facilities is the use of MPC with lightweight aggregate. This option results in extending pavement life by approximately 15 times; however, this is an expensive option. The use of ordinary PCC with lightweight aggregate extends the life of the pavement by approximately 4 times and is much more cost-effective than using MPC-based concrete. This solution has been employed at Oceana Naval Air Station (NAS) under F/A-18 aircraft with excellent results and is recommended for moderate climate areas where thermal gradients are less severe (NFESC TDS-2058-SHR).

7.3. Laboratory testing using accelerated heating cycles that simulate APU conditions under B-1 aircraft has identified that the E-Krete™ coating becomes rubbery after continuous exposure to turbine fluid combined with high heat (175 °C [347 °F]) and allows the fluids to reach the underlying substrate. This rubbery condition is consistent with field observations at McConnell AFB; however, the use of E-Krete™ at McConnell AFB has been considered to be successful at preventing concrete deterioration. Polyurea (ElastoKast 95™) coatings have been successful in the laboratory at preventing aviation lubricants (hydraulic and turbine fluids) from penetrating to the substrate at high temperatures, but have not been field-tested. Surtreat® has not been laboratory tested at this time.

7.4. Test areas at Robins AFB treated with Surtreat® have not been in use long enough to provide useful data.

7.5. The use of steel plates at Dyess AFB has been marginally successful. Initially, the steel plate provides protection for the concrete but, with time, as the B-1 fluids soak into the area surrounding the steel plate, the concrete eventually softens and begins to ravel. This may take 5 to 15 years, depending on the amount of use the pad gets. Eventually, the pad must be reconstructed.

7.6. Periodic and aggressive cleaning of concrete pads with environmentally friendly detergents to remove fluids has been shown to significantly extend the concrete life in laboratory testing (Hironaka, Malvar, pp. 32-35.).

8. Recommendations.

8.1. At Dyess AFB, the use of MPC with a non-acid reactive aggregate (a basalt) has provided the best performance to date of all the mitigation strategies in use at Air Force

facilities. Based on the laboratory studies conducted by NFESC, use of MPC with a lightweight aggregate may provide even better performance; however, the use of MPC with any aggregate is an expensive repair option.

8.2. At Oceana NAS, the use of ordinary PCC with lightweight aggregate has provided good performance; this combination is likely to provide the best cost for performance. Laboratory studies by NFESC show the service life of this material to be approximately four times that of ordinary PCC.

8.3. E-Krete™ use at McConnell AFB had problems with delamination and swelling although it prevented serious concrete deterioration as of fall 2001. It is scheduled for application on new PCC B-1 loading pads at McConnell AFB in 2002.

8.4. The use of Surtreat® at Robins AFB has not been in service long enough to make any specific recommendations about its use. It is scheduled to be applied on new PCC B-1 loading pads at McConnell AFB in 2002.

8.5. For existing concrete pads, periodic and aggressive cleaning of the concrete with environmentally friendly detergents to remove fluids can significantly extend the life of the pads.

8.6. This ETL will be revised and updated as more information on mitigation and repair strategies becomes available.

9. Points of Contact. Recommendations for improvements to this ETL are encouraged and should be furnished to:

U.S. Army Engineer Research and Development Center, CEERD-GM-A3909, Halls Ferry Road, Vicksburg, MS 39180-6199, Dr. Kent Newman, DSN 446-3858, commercial (601) 634-3858, email john.k.newman@erdc.usace.army.mil

HQ AFCESA/CESC, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, Attention: Mr. Jim Greene, DSN 523-6334, commercial (850) 283-6334, FAX DSN 523-6219, email james.greene@tyndall.af.mil.

MICHAEL J. COOK, Colonel, USAF
Director of Technical Support

2 Atchs
1. Field Observations
2. Distribution List

FIELD OBSERVATIONS

A1.1. McConnell AFB, Kansas.

Note: The point of contact is Lt. Col. Jim Miller, Air National Guard, 184th CES/CC, email: James.Miller@ksmcco.ang.af.mil, telephone: (316) 687-7802.

A1.1.1. In November 1998, three E-Krete™ “pads” approximately 4.5 meters by 4.5 meters (15 feet by 15 feet) in diameter were constructed at parking areas B10, B11, and B12. The materials were placed under clear skies and with temperatures between 7 to 16 °C (45 to 60 °F); winds were high and gusting. The pavement temperature ranged from 10 to 27 °C (50 to 80 °F). Area B10 was overlaid with three coats of E-Krete™ to a total thickness of approximately 3 to 5 millimeters (0.125 to 0.1875 inch). Two layers of E-Krete™ with a fuel-resistant clear topcoat sealer were placed on B11. Two layers of E-Krete™ only were placed on B12. All three areas were placed on relatively new concrete (about two months old), but with substantial hydraulic fluid staining. The areas were pressure-washed only before E-Krete™ placement; no detergent or solvents were used to clean the surface. The concrete joints were covered with masking tape during application.

A1.1.2. Two months after placement of E-Krete™, it was noted that delamination was occurring in some areas and that the coating had become rubbery in areas that were severely stained with JTF. An inspection revealed that the delamination was progressing from the concrete joints towards the center of the slabs. After discussions with Polycon representatives and the E-Krete™ placement crew, it was discovered that the masking tape covering the joints was not removed until well after the E-Krete™ had begun to harden. While removing the tape, some of the coating stuck to the tape and pulled away from the slab. It was in these areas that delamination occurred; it was also in these areas that aircraft fluid had stained the concrete before E-Krete™ had been applied. It was surmised that the fluids on the concrete had prevented a proper bond of the E-Krete™ to the concrete substrate. Removal of the masking tape from the joints pulled up some of the coating because it was prevented from bonding to the concrete by the fluid, providing additional avenues for the fluids to migrate under the coating.

A1.1.3. A detailed inspection of the pads was conducted In November 2000. The overall condition of the E-Krete™ was described as “fair.” Approximately 10 to 15 percent of the E-Krete™ surface had delaminated, with severe staining from aircraft fluid. In pads B10 and B12 the E-Krete™ had turned rubbery. This rubbery condition is due to swelling of the polymer within E-Krete™ by JTF. The condition of the E-Krete™ on pad B11 (Figure A1.1) was better than on pads B10 (Figure A1.2) and B12, but some rubbery areas were noted. Despite this condition, the E-Krete™ prevented the aircraft fluids from causing serious damage to the underlying concrete substrate. Given that concrete replacement under the B-1 aircraft generally occurs every two years, the performance of the E-Krete™ coating was considered successful. Delamination of the E-Krete™ occurred from poor adhesion due to existing aircraft fluids already present on

the concrete and proceeded from the joints towards the center of the concrete slab (Figure A1.3). Further use of the E-Krete™ product is planned at McConnell AFB in 2002.



Figure A1.1. Pad B11 Soaked with Hydraulic and Turbine Fluid



Figure A1.2. Pad B10 Soaked with Hydraulic and Turbine Fluid



Figure A1.3. Pad B11 Joint, Showing Delamination and Blistering

A1.2. Robins AFB, Georgia.

Note: The point of contact at Robins AFB is Maj. Mark Byrd, Air National Guard, 116th CES, email: mark.byrd@garobi.ang.af.mil, telephone: (478) 327-5800.

A1.2.1. B-1 Spots. The B-1 aircraft had been parked on this area for eleven months (since September 2000). Most “spots,” as they are referred to at Robins AFB, were in excellent condition; very little cracking was observed. The joint sealants were swollen but appeared to be holding up well, and was reported to be Federal Specification (FS) SS-S-1614, *Sealants, Joint, Jet-Fuel Resistant, Hot-Applied*. Hydraulic fluid was easily spotted due to its red color; JTF and lubricating oils appeared as amber-gold or brown. Leaking JTF under the engines/APU was also apparent (Figure A1.4). There were two different types of concrete in use and one concrete surface treatment: PCC with Georgia limestone aggregate; PCC with Iron Mountain traprock from Missouri; and PCC with Georgia limestone aggregate with Surtreat[®] concrete sealer. No deterioration was noted other than some minor shrinkage cracking (Figure A1.5).



Figure A1.4. Typical Spot Staining



Figure A1.5. Spot 2 Shrinkage Cracks

A1.2.2. Christmas Tree (Old Alert Apron). B-1 aircraft were parked on this apron, composed of 50-year-old concrete, for approximately two years. Some surface cracking in the old concrete was observed but most of the concrete slabs appeared structurally sound. The old concrete had a mottled, moldy surface. Some slabs had obviously been replaced and those showed more damage. The damage was typical of that observed under B-1 aircraft. The damaged concrete exhibited severe scaling and surface concrete paste was delaminating in sheets (Figures A1.6 and A1.7).



Figure A1.6. Close-up View of Scaling at Old Alert Apron



Figure A1.7. Scaling at Old Alert Apron

A1.3. Dyess AFB, Texas.

Note: The point of contact at Dyess AFB is Mr. Larry Webb, email: james.webb@dyess.af.mil, telephone: (915) 696-5620.

A1.3.1. The B-1 aircraft were parked on the same apron in two rows: A and B. There were approximately 35 parking pads in each row labeled as A1 through A35 and B1 through B35. The active pads were mainly A1 through A10 and B1 through B10. The areas under the B-1 APU were of three types: conventional PCC; steel plates bolted to the PCC pavement; and MPC (Set 45™). Approximately 40 pads were inspected; of those, several were inspected in detail: pads A5 and A6 with steel plates; B2, B4, and B5 with MPC; and B12 with PCC. Most of the occasionally used B-1 pads were PCC, most of the active pads were steel plates, and a few of the active pads were MPC. Those pads with steel plates are being replaced with MPC as funds allow. Temperatures of approximately 200 °C directly under the B-1 APU have been measured.

A1.3.2. The joint seals on the B-1 apron were FS SS-S-200E, *Sealants, Joint, Two-Component, Jet-Blast Resistant, Cold-Applied*, and were performing extremely well except in areas where the joints were directly below the APU. The seals had noticeably softened and partially blown out of the joints; however, very little swelling of the seals in areas were noted where hydraulic and turbine fluids had soaked the joints.

A1.3.3. The MPC (Set 45™) was selected after reviewing the available literature (TDS-2058-SHR). PCC deterioration had begun to proceed beyond the edges of the steel plates. The Set 45™ was extended by approximately 50 percent by using a basalt aggregate that was stable in the presence of muriatic acid. The aggregate was chosen because research had shown that concrete deterioration was resulting from the production of acids under the B-1 APU. The primary chemical component of the JTF employed in the B-1 engines is an ester that degrades to an acid in the presence of heat. The acids then react with the basic PCC, destroying the structural integrity of the concrete as the acid slowly consumes the cement. This may also eventually occur with the Set 45™ because of its basic chemical composition; however, to date this has not been observed in practice.

A1.3.4. The construction of the Set 45™ pads was completed in a checkerboard fashion using slabs no larger than 1.5 meters by 1.5 meters (5 feet by 5 feet) (Figure A1.8). An area approximately 12 meters by 7.5 meters (40 feet by 25 feet) was replaced. The existing concrete was sawcut (where necessary) to a depth of 76 millimeters (3 inches) and the concrete removed with a jackhammer. The prepared surface was then drilled to provide anchors for the forms and the forms were placed. The Set 45™ was then placed in a checkerboard fashion where the “red” squares were filled, the forms removed, and the “black” squares filled using the new Set 45™ slabs and the old concrete as the forms for the second round of Set 45™ placements. A small concrete mixer was employed to mix the Set 45™/basalt mixture. Each form was filled and the surface finished before proceeding to the next form. Some shrinkage cracking

of the Set 45™ slabs was noted but it was not severe.



Figure A1.8. MPC “Checkerboard” Repair Area

A1.3.5. The oldest Set 45™ pad (B12) was approximately two-and-a-half years old and holding up well. No cracking or loss of surface paste due to the combination of APU heat and turbine fluid was noted. Several new Set 45™ pads had been placed in the past year and were also holding up well. No cracking or loss of surface paste was noted on these pads.

DISTRIBUTION LIST

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SPECIAL INTEREST ORGANIZATIONS

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